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TASK OBJECTIVES

        Most of this period was focussed on validation planning and
activities, ATBD version 2 preparation and submittal, and panel review and
response of the vegetation index, ATBD. Continued research was oriented
towards the following:

*   level 3 vegetation index compositing methodology;
*   NDVI continuity with AVIRIS data;
*   Quality assurance document
*   NDVI saturation problem and the use of the green channel;
*   VI - biophysical analysis

WORK ACCOMPLISHED

1.   Version 2 ATBD

        The second version of the vegetation index ATBD was completed and
is available via anonymous ftp at brazil.agshantz.arizona.edu. The revised
ATBD is considerably larger due to the addition of the level 3 compositing
approach and the validation document.   The second vegetation index
presented is primarily oriented toward improved vegetation biophysical
analysis, rather than a reduction in the noise of vegetation indices. Much
emphasis was placed on making the new vegetation index linear and in
reducing the 'saturation' problems encountered in the NDVI.   As stated in
the document, it is difficult to monitor vegetation and detect seasonal and
inter-annual changes in vegetation in a "saturated" mode.

        We also investigated the relatively 'narrow', MODIS red bandwidth
to determine if chlorophyll absorption sensitivity would render the MODIS
NDVI too sensitive to vegetation, thus saturating earlier or at lower
amounts of vegetation. We found that the MODIS red band is superior in
performance to that of the TM and AVHRR and that it will present no problem
in vegetation monitoring with the MODIS instrument. Saturation problems in
the NDVI are attributed to the non-linear transform in deriving the NDVI
from the simple ratio (NIR/red) and to improved atmospheric correction
algorithms. The new indices proposed are named 'enhanced' vegetation
indices due to its linearity over a wider range of vegetation conditions
from deserts to dense forests.

2. Temporal and Spatial Compositing of MODIS VIs (Level 3)

        The goal of the MODIS compositing algorithm is to preferentially
select near-nadir view, cloudless pixels, ensuring the quality and
consistency of the composited data, while optimizing the spatial
resolution, atmosphere correction and the BRDF correction of angular
effects. The influence of variable sun-target-sensor configurations on
derived vegetation indices can be standardized in various manners,

including (1) standardize reflectances to nadir view angle at
representative solar zenith angle; (2) standardize reflectances to nadir
view angle and constant (smallest) solar zenith angle; (3) use of spectral
(hemispherical) albedos; or (4) adjust to a constant 'off-nadir' view angle
with constant sun angle. For the standard MODIS VI products, we propose to
use the first two methods and examine the other two approaches post-launch.
Emphasis was placed recently on further development of the current V1
MODIS composite algorithm (@250 m) and its associated quality assurance
aspects. NOAA-AVHRR, ASAS and PARABOLA sensor data were used to test and
evaluate the best possible and consistent solution on a global scale as
well as to show the accuracy of the different composites in selecting
near-nadir, cloudless pixels.

2.1   Different composite scenarios: multitemporal AVHRR data results

        Seven different vegetation index composite scenarios were designed
with the goal of achieving cloud-free, near-nadir, atmospherically clean
imagery. Each composite scenario starts with a method which has the best
solution followed by an alternative or 'backup' solution for less ideal
data:

1.   Maximum value composite scenario (MVC)
2.   Minimum view angle composite scenario (MV-MVC)
3.   View angle threshold composite scenario (TV-MVC)
4.   Constraint view angle composite scenario (CV-MVC)
5.   Three method composite scenario (TV-MVC/BRDF/MVC)
6.   BRDF based and MVC composite scenario (BRDF/MVC)
7.   Version 1 MODIS composite scenario (BRDF/CV-MVC/MVC)

        Global, NOAA-AVHRR 8km-Pathfinder data were used to demonstrate the
advantages and disadvantages and nadir-view accuracy of each composite
methodology. The data were atmospherically corrected for Rayleigh and ozone
only and came with a cloudmask. The seven different vegetation index
composite scenarios were applied and analyzed with their corresponding QC
images for 32 days of data. For each pixel, the QC flags included
information about data integrity, clouds and the composite technique
selected for each scenario. The NDVI-MVC scenario overestimated the NDVI
between 4 and 18 % depending on the continent and composite scenario it was
compared to.

        The minimum view angle VI composite (MV-MVC) showed view angle
discontinuities and problems with clouds, despite the use of the QC flags.
The latter caused lower NDVI values for each continent because days with
cloudy pixels were included in the NDVI composite. It selected cloudy
pixels in cases where the cloud mask was not working well. The view angle
threshold TV-MVC approach by itself caused some discontinuities in the NDVI
images related to view angle effects, especially over desert areas and
areas with low cloud cover during the 16 day composite period. The
constraint view angle CV-MVC approach was the best approach of the MVC
related approaches. It had few artifacts and had better cloud screening
capabilities. The NDVI results from the composite scenario 5 was very
similar to the composite scenario 6 and 7. However the main disadvantage of
this three-way composite scenario was the discontinuities that are caused
by the view angle threshold.

The two BRDF based scenarios had few discontinuities, although some speckle was observed which was caused by cloud contamination and possible misregistration of pixels. It has the advantage in averaging the 16 days of observations. The BRDF also tends to extrapolate the spatial resolution from the larger pixel sizes to the finer pixel resolution. The current version 1 MODIS algorithm, BRDF/CV-MVC scenario, was considered to represent a composite period best. The NDVI was 6 to 18 % lower for this composite scenario compared to the MVC. It should be noted that for scenarios 6 and 7, large portions (about 40 %) of the continents were BRDF corrected, but lack of cloud free data always caused the secondary solution to take into effect, which is close to the MVC. If more pixels would be standardized to nadir the difference between MVC and BRDF based scenarios would be even larger.

The seventh scenario (V1 BRDF/CV-MVC/MVC) was selected because it had few spatial artifacts and showed to have the best view angle distribution close to nadir and thus the least pixels with larger view angles. For most composite scenarios the view angle distributions (outside the view angle threshold or about nadir) are skewed towards the forward scatter view angles. Different continents have preferential selection of forward view angles e.g. around 23˚ for Africa, Asia and Europe, 38˚ for Australia and North America and both 13˚ and 48˚ for South America.

2.2 Multitemporal AVHRR Compositing over 1 year

The composited NDVI was recently produced for 23, 16-day composite periods (Jan 1 1989 – Jan 3 1990), using daily AVHRR red and NIR normalized reflectance data at 8 km resolution. The current MODIS V1 and MVC composite scenarios were applied and analyzed with their corresponding QC images. The input data and the composite results of 30 distributed sites were extracted for all 23 composite periods. Each site was 3x3 pixels. Temporal VI profiles of the MVC and V1 composite scenarios show the V1 scenario to produce NDVI profiles which are equally smooth or smoother than the MVC approach. Statistics on cloud frequency and the applied composite method are currently being analyzed, as well as the quality of the BRDF data. Results from enhanced VIs are being analyzed with respect to saturation and spatial continuity.

2.3 Accuracy of BRDF models to estimate reflectance values (PARABOLA)

Privette studied the overall accuracy of 10 simple BRDF models in estimating the nadir reflectance. The 10 models were inverted with subsets of ground-based PARABOLA data (red and NIR) collected over nine land surface cover types. Land cover types included soil, grassland, cotton, shinnery Oak, Black Spruce, Spruce Hemlock, Aspen, Jack Pine, and lava soil. The accuracy of the BRDF models to estimate nadir reflectances at one solar zenith angle was examined. The Rahman model performed best, closely followed by Ross-thin/Li-sparse and Roujean's and than the modified Rahman and Ross-thick/Li-sparse models.

2.4 Solar Zenith Angle effects on VI (PARABOLA)

The potential errors due to the variable solar zenith angle between different days and swaths (20˚ max) can be estimated by using ground (Parabola) data for different vegetation cover types. For a solar zenith angle range of about 40˚, the mean relative difference in the VI is about 18% for the NDVI and about 31% for the SAVI. It is estimated that the differences within a swath are about half off these relative difference values. Considering the large solar zenith angle changes in the mid- and high latitudes, seasonal changes easily can cause relative differences of 20 % in the NDVI.

The albedo derived VIs were less sensitive to solar zenith angle changes as indicated by the lower coefficients of variation and mean relative differences. However, the difference between the reflectance derived VI and the albedo derived VI indicated that each VI would need to be interpreted differently and that separate biophysical translations would be required. At the moment, the normalization of the 8-day and 16-day, level 3 vegetation index products for sun angle effects is mostly left as a post-launch effort.

2.5   BRDF models and VI compositing scenarios (ASAS)

High spectral resolution bidirectional reflectance factor (BRF) measurements from the Advanced Solid State Array Spectroradiometer (ASAS) instrument flown at ~5000m altitude over various field campaigns were used to simulate the MODIS sensor, evaluate the accuracy of simple linear BRDF models in estimating nadir-equivalent VI values, and evaluate the effect of view angle distribution on the performance of the BRDF models.

The ASAS reflectance data were convolved into the first three MODIS bands (red, NIR, blue; 620-670 nm, 841-876 nm, 459-479 nm) and corrected for atmosphere effects using aircraft and ground sunphotometer optical depth measurements with "6S" (Vermote, E). Major land cover types included in this study were deciduous and coniferous forest (Oregon Transect Ecosystem Research Project - OTTER, Boreal Ecosystem Atmosphere study- BOREAS), grassland (First ISLSCP Field Experiment - FIFE) and shrub savanna sites (Hydrologic, Atmospheric pilot Experiment in the Sahel - HAPEX-Sahel). Based on the findings of the PARABOLA experiment and the previous ASAS research, the four best BRDF models were included in the evaluation: Walthall, Roujean, Ross-thin/Li-sparse and Ross-thick/Li sparse. The non-linear Rahman model was excluded because of its computationally- intensive fitting procedure, which is operationally not practical. The mean difference (error) in reflectance values is generally lower than 0.006 for the red waveband for the Walthall, Roujean and the Ross_thin/Li_sparse models. The error of the predicted nadir reflectance values in the NIR was generally lower then 0.0075 for the Walthall, Roujean and the Ross_thin/Li_sparse models. The error in the predicted nadir reflectance values for the Ross_thick/Li_sparse was generally higher than the other three models for both bands. The error in the predicted reflectance values is generally the largest for view angle distributions that lack forward scatter observations.

The mean difference (error) in VI is generally between 0.002 and 0.02 for the NDVI for the Walthall, Roujean and the Ross_thin/Li_sparse models. The error in the predicted nadir VI values for the

Ross_thick/Li_sparse was generally higher than the other three models. The mean absolute difference between the measured nadir VIs and the VIs resulting from the different composite scenarios were computed for all vegetation types and view angle distribution combination. The errors due to the MVC approach (MVC-NDVInadir) and the maximum error due to non standardization (or range) of the NDVI (NDVImax- NDVImin) were computed as a reference. The absolute error due to the BRDF approach is three times smaller than the error in the MVC approach and about 10 times smaller than the error using an NDVI without standardization (full NDVI range).

The error in the predicted VI values is generally the largest for view angle distributions that lack forward scatter observations. The Ross_thin/Li_sparse model in particular showed some large errors for the old black spruce vegetation type, where it predicted negative reflectance values. NDVI values derived from the BRDF model are underestimated with respect to the measured nadir NDVI.

The BRDF models were ranked going from best to less good: Walthall, Roujean, Ross_thick/Li_sparse, Ross_thin/Li_sparse. This ranking is in agreement with the results in Table 10. For these data sets, the Roujean and Walthall BRDF models were more accurate then the Ross_thick and Ross_thin models. Ross_thin had several outliers. The overall performance of the Ross_thick model was the least accurate in terms of the prediction of nadir VI. The results do show that all models perform best for low and medium density vegetation covers. Differences in relative azimuthal plane can cause significant differences in the performance for each model e.g. Grassland, Old Aspen and Old Black Spruce.

2.6   Anisotropy of the enhanced VIs (ASAS)

Bidirectional reflectance factors affect the anisotropic behavior of the NDVI significantly. The enhanced VIs are also affected in different ways by the BRDF. Our results have shown that most VIs have a backscatter (or sunlit) bias for higher VI values, opposite that of the NDVI, which favors the darker (shaded) view direction. These results also show the simple ratio (NIR/red) to be very sensitive to view angle effects. This is a very important finding because this states that ratios do not alleviate bidirectional view angle effects and it is not the ratioing properties of the NDVI that render this index less sensitive to view angle effects. If NDVI angular behavior at higher levels of vegetation is invariant due to signal compression, then the use of the maximum NDVI value as a 'backup' criterion will have to be re-assessed.

2.7   MAS data

Several MAS (MODIS Airborne Simulator) images from the SCAR-B experiment were processed to apparent reflectances to evaluate the anisotropic effects on surface reflectance and vegetation indices due to view-sensor geometry. Future research will involve the middle- infrared (less sensitive to smoke) and thermal bands (cloud mask) to determine if they can aid in the compositing of vegetation indices. This is an ongoing activity that was just started in December 1996.

2.8   AVHRR prototyping and code development for VIs and QA

        Parallel to the version 1 MODIS vegetation index compositing code a
research version has been developed to trace the input and output of the
current composite algorithm and compare this to the traditional maximum
value composite approach. The research code provides the means to evaluate
the accuracy of the BRDF algorithm/VI product as well as a means to develop
tools for quality assurance flags and metadata. Furthermore, enhanced
vegetation index equations (SAVI, DVI and SR) were implemented to evaluate
their behavior. The HDF library and c-code were integrated more
efficiently which improved the speed of a composite run significantly
(about 4 times faster). Our programmer has been optimizing the code further
by switching floating point operations to integer operations where
possible. This is an ongoing effort.

3. NDVI continuity relationships

        Data from six different AVIRIS scenes were processed to simulate
the NDVI of the MODIS, AVHRR, and Landsat TM sensors to establish
preliminary translations between the AVHRR-NDVI data series with that of
the MODIS NDVI. Our goal was to outline a relationship between MODIS- NDVI
and AVHRR- NDVI over target sites which included soils, forest,
agriculture, burned, and mixed sites. The images used were from the SCAR-B
project, specifically from the areas of Campo Grande, Ji- Parana, North
Brasilia, and Porto Velho (Brazil).

When the NDVI was computed from equivalent data sets, I.e., using
atmospheric corrected data ('6S'), atmospherically uncorrected data, or
partially atmospheric corrected (Rayleigh and ozone) data, the
relationships between the MODIS and AVHRR - NDVIs were quite linear and
easily translatable. Some deviations were related to differences in target
spectral characteristics (e.g. vegetation and soils), and differences
associated with sensor bandwidth and the atmosphere absorption windows for
water vapor. The AVHRR has much wider NIR and red bands than MODIS.

        However, when the AVHRR NDVI is computed from Rayleigh and ozone
corrected reflectances (current processing) and the MODIS NDVI is computed
from atmospherically corrected reflectances (anticipated processing), then
the relationships for continuity purposes become more complex and there is
much more deviation in the respective values, with the MODIS NDVI always
yielding higher values than that of the AVHRR. This will be the focus of
more study, not only for continuity purposes but for 'saturation' issues as
well. We plan to conduct a much more thorough analysis of all factors
influencing continuity relationships. This will involve more precise
atmospheric correction with aerosol optical depth parameters from the
AERONET database of Brent Holben et al.. More AVIRIS scenes with less smoke
will be selected for a range of global vegetation types to improve global
representation.

4. Chile - Validation Exercise

        A two week field campaign was conducted in the arid and humid zones

of Chile in September 1996. Both sites are MODIS test sites and part of the Global Land Cover Test Sites (GLCTS) initiative being coordinated by Ken McGwyer. Brent Holben joined the exercise at the northern site, named Coquimbo, and installed a Cimel sun photometer at the Las Cardas Experimental Station , University of Chile. The area lies in an arid/ semiarid transition zone and is dominated by grasses. Wim van Leeuwen, myself, and participants from the University of Chile conducted ground based and light aircraft radiometric and biophysical measurements. Four-band exotechs were utilized on the ground as well as in light aircraft to make simultaneous measurements.

At the southern, Osorno site. We conducted the experiment within Puyehue National Park, again with simultaneous light aircraft and ground based measurements. The site is an old growth, evergreen broadleaf rainforest in the Andes Mountains. Ground-based measurements consisted of canopy transmittance measures and ceptometry readings for LAI and fAPAR. Jeff Privette from MODland participated in the experiment and investigated some of the BRDF issues posed by the test sites. Aircraft data included surface reflectance measurements. At both sites stereo color photos were taken to document the test sites.

5. Validation plan activities

The main objective of validation work is to design empirical or semi-empirical robust vegetation measurements applicable over all terrestrial biomes. The NDVI has been used over the last two decades as a tool for measuring biophysical activity of vegetated surfaces. The existing VIs have limitations associated with angular effects, saturation and non-linearity, canopy structural influences, background contamination etc. The criteria for a global vegetation index is that it should optimize the sensitivity range over as wide a range of vegetation conditions as possible; normalize external and background effects; and be coupled with biophysical parameters. There is a need to validate the currently available VIs in light of these criteria. Components of VI validation plan are:
*   comparison with results from radiative transfer code models
*   comparison of VI outputs with observational field data
*   comparison with aircraft data
*   comparison with existing satellite sensor outputs
*   comparison with future satellite data
*   comparison with bioclimatic model outputs.

Currently the first two components are being actively pursued with respect to biophysical coupling in a global sense. Use of radiative transfer canopy models (RTC) is being cooperatively done with Dr. Myneni. Field data from the past experiments in different parts of the world are being used to validate all the VIs. Data from Superior National Forest (collected by NASA), Walnut Gulch, FIFE, BOREAS, and Hapex-Sahel are currently being summarized.   Thus far, the VI-LAI or VI-fAPAR relationships for low-vegetation areas tend to cluster over a small range. So does the higher amounts of vegetation at the higher range.

5.1   VI test sites:

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Site name                 lat/long                      veg
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*proposed MODLAND study sites (for all):

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* 1) Harvard forest, MA        42.37N / 72.25W        deciduous forest
* 2) La Jornada, NM            32.5N / 106.75W        grass/shrub
* 3) Pampas, Argentina         31.2S / 58.0W          humid tallgrass
* 4) Kalahari, S. Africa       19.2S / 27.3E          woodland savanna
* 5) Maricopa, AZ              33.04N/ 111.58W         agriculture
* 6) ARM-CART, OK              36.37N / 97.3W          grass/agriculture
* 7) Walker Branch, TN         35.9N / 84.3W           forest
* 8) LBA forest Brazil         2.28S / 60.09W          broadleaf forest
* 9) Howland, MN               45.3N / 68.8W           deciduous  forest
* 10) Kasungu, Malawi          13.05S / 33.1E          seasonal woodland
* 11) H.J. Andrews,Oregon      44.2N / 122.2W         coniferous forest
* 12) Tver, Russia             51.0N / 82.5E           agriculture
* 14) tundra, Russia           56.5N / 92.5E           tundra/forest
* 15 Tomsk, Russia             56.5N / 85.0E
* 16) Norilsk, Russia          66.5N / 88.0E           forest
* 17) Las Chicas, Argen        37.5S / 59.5W
* 18) Rio Mayo, Argen          45.75S / 68.0W
* 19) BOREAS-SSA, Can          54.0N / 105.1W
* 20) BOREAS-NSA, Can          55.9N / 98.5W
* 21) Olancho, Honduras        15.0N / 86.7W           mixed forest
* 22) Ji-Parana, LBA           10.14S / 61.52W         pasture
* 23) Sao Gabriel, LBA         0.28N / 66.36W          primary forest
* 24) Santarem, LBA            3.53S / 54.55W          forest
* 25) California & Nevada      34.5-39.5N /115-112W    agriculture
* 26) La Selva, Costa Rica     10.43N / 84.03W         moist forest
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Additional sites for vegetation index validation activities include:

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1) Arctic tundra , AL          29.27N / 103.22W        tundra
2) Central plains, CO          40.83N / 104.7W         shortgrass prairie
3) Konza prairie, KS           39.08N / 96.62W         tallgrass prairie
4) Walnut Gulch, AZ            31.74N / 109.85W        dry grassland
5) Mapimi, Mexico              26.68N / 103.75W
6) Ubsu Nur, Mongolia          50.25N / 92.58E         grassland
7) Caatinga, Brazil            07.0S / 36.0W           thorny scrub
8) Coquimbo, Chile             30.0S / 71.0W           mediterranean
9) Llanos, Venezuela           7.8N / 66.5W            grassland
10) Osorno, Chile              40.5S / 73.0W           humid forest
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5.2   La Jornada meeting '97

        This meeting was held in Las Cruces, NM on January
13-15, 1997. Jeff Privette, Wim van Leeuwen, Faiz Rahman attended the
meeting on behalf of MODIS team. Jim Conel attended on behalf of MISR and
Kurt Thome attended on behalf of ASTER. Eleven scientists from USDA ARS
and the LTER project were present in the meeting. La Jornada is a large

valley with mainly three distinct biome associations, i.e., grass, shrub, and transitional (shrubs taking over grass). The area is arid and the brushland is not suitable for field work, at least at the early stages of validation, due to the topography and vegetation scarcity. The grassland is very suitable for the validation prototyping fieldwork. It's a plain homogeneous area with a low but steady vegetation over the whole year. Current plans are to conduct a validation prototyping exercise in May, 1997. Our vegetation index group, however, may appear on a monthly basis to conduct seasonal measurements, culminating with another prototyping campaign in late September, 1997.

6. Presentations

        Abstracts were submitted for presentation at the next "physical measurements and spectral signatures" symposium in Courchevel, France, April 1997, as well as for the next IGARSS'97 Symposium:

1. "Quality assurance of global vegetation index compositing algorithms using AVHRR data"   by Wim J.D. van Leeuwen*, Trevor W. Laing, Alfredo R. Huete (to be presented at IGARSS'97).

2. "The use of vegetation indices in forested regions: issues of linearity and saturation" by Alfredo R. Huete, Wim J.D. van Leeuwen and Huiqing Liu ((to be presented at IGARSS'97).

3. "Bioclimatic and vegetation index based derivation of biophysical parameters: a Chilean example" Huete,A., Santibañez,F., de Lira,G., van Leeuwen, W.., Morales,L., De la Fuente,A., Uribe,J.

4. Presentation at the BRDF workshop at GSFC, Jan. 1997, on vegetation index limitations for biophysical parameter retrievals.

7.   Anticipated future action

*   Three months of 1km NOAA AVHRR data is currently being processed at NASA/GSFC with our research code to evaluate the composite approach at finer spatial resolutions.

*   Standardization of VI to nadir view and a certain sun angle is being investigated for a monthly climate modeling grid VI product. Monthly compositing would ensure sufficient input data for BRDF determination using inversion of a simple BRDF model (Rahman's). The VI would be globally normalized to a constant solar-view geometry (possibly determined by the angle most sensitive to canopy biomass) at 0.25˚ spatial resolution (25 km). At the lower temporal resolution, this product would be catered towards modelers and those doing interannual comparisons.

*   Work on biophysical translations from vegetation index to LAI, biomass, and fAPAR.

*   Error budgets for the vegetation indices and for the validation.

*   archiving all the existing VI and Biophysical data from different
        experiments.

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